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Evolution of the eastern volcanic ridge of the Canary Islands based on new K–Ar data

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ABSTRACT

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The results of 64 new K–Ar age determinations, together with 32 previously published ages, show that after a period of erosion of the basal complex, Miocene volcanic activity started around 20 Ma in Fuerteventura and 15 Ma in Lanzarote, forming a tabular succession of basaltic lavas and pyroclastics with a few salic dykes and plugs. This series includes five separate volcanic edifices, each one with its own eruptive history. In Fuerteventura, several Miocene eruptive cycles have been identified: in the central edifice one around 20–17 Ma, followed by two others centred around 15 and 13 Ma; in the southern edifice the maximum of activity took place around 16–14 Ma, whereas in the northern one the main activity occurred between 14 and 12 Ma. In Lanzarote a first cycle of activity took place in the southern edifice between 15.5 and 14.1 Ma, followed by another between 13.6 and 12.3 Ma. In the northern edifice three pulses occurred: 10.2–8.3, 6.6–5.3 and 3.9–3.8 Ma. An important temporal gap, greater in Fuerteventura than in Lanzarote, separates Series I from the Plio-Quaternary Series II, III and IV, formed by multi-vent basaltic emissions. In Fuerteventura the following eruptive cycles have been identified: 5, 2.9–2.4, 1.8–1.7, 0.8–0.4 and <0.1 Ma. In Lanzarote, the activity was fairly continuous from 2.7 Ma to historic times, with a maximum in the Lower Pleistocene.

Eruptive rates in the Series I edifices were on the average 0.1–0.01 km^3/ka, comparable but slightly smaller than in similar edifices in Tenerife and La Gomera, but much lower than in Gran Canaria. Average post-Miocene eruptive rates were about 0.013–0.027 km^3/ka in Lanzarote and 0.003–0.007 km^3/ka in Fuerteventura.

All these volcanic edifices show a similar general sequence (fissural eruptions, erosion, multi-vent volcanism), repeated at different periods in different parts of the eastern islands of the Canaries. The model of growth of the Series I edifices is comparable to those in Tenerife and La Gomera: long periods of activity, sometimes greater than 6 m.y., with pulses separated by gaps. However, salic and intermediate differentiates, frequent in Tenerife and La Gomera, are very scarce in these islands. The Fuerteventura–Lanzarote ridge shows a decrease in volcanic activity with time, and also a certain SSW–NNE polarity in the temporal development of volcanism.

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Geological setting

In contrast with the rest of the Canaries, which constitute isolated volcanic edifices separated by depths greater than 3000 m, Fuerteventura and Lanzarote are part of a ridge roughly parallel to the African coast (Fig. 1). Geophysical work in the area (Beck and Lehner, 1974; Uchupi et al., 1976; von Rad and Arthur, 1979; Dañobeitia and Collette, 1989) has shown that, in addition to the main volcanic topography, emergent like Lanzarote and Fuerteventura or submerged like the Banco de la Concepción (Weigel et al., 1978), there are smaller reliefs aligned in the same NNE–SSW direction.

Two major formations can be distinguished in these islands: a basal complex and younger, subaerial volcanic series. The basal complex (Fúster and Aguilar, 1965; Fúster et al., 1968b; Stillman et al., 1975; Robertson and Bernouilli, 1982; Le Bas et al., 1986; Robertson and Stillman, 1989; Ibarrola et al., 1989a) is exposed in the western central part of Fuerteventura (Fig. 2). It consists of Cretaceous turbidites overlain by interbedded Albian–Oligocene sediments and submarine volcanics, which are intruded by a very dense dyke network and alkaline plutonics. K–Ar whole-rock ages of 48±2 Ma from a dyke (Le Bas et al., 1986) and 35.7±1 Ma on biotite separates from a submarine volcanic rock (Ibarrola et al., 1989a) have been obtained for this complex. As the K–Ar method is probably not adequate to set up a correct chronology in this basal complex, because of its complex thermal history, this paper concentrates on the submarine volcanics. In Lanzarote the basal complex does not crop out, but a deep borehole in the centre of this island has revealed the presence, at depths of 900–2700 m (Sánchez-Guzmán and Abad, 1986), of submarine volcanics and sediments which could be equivalent to that complex.

The subaerial volcanic series, which are the subject of this work, are, in turn, comprised of

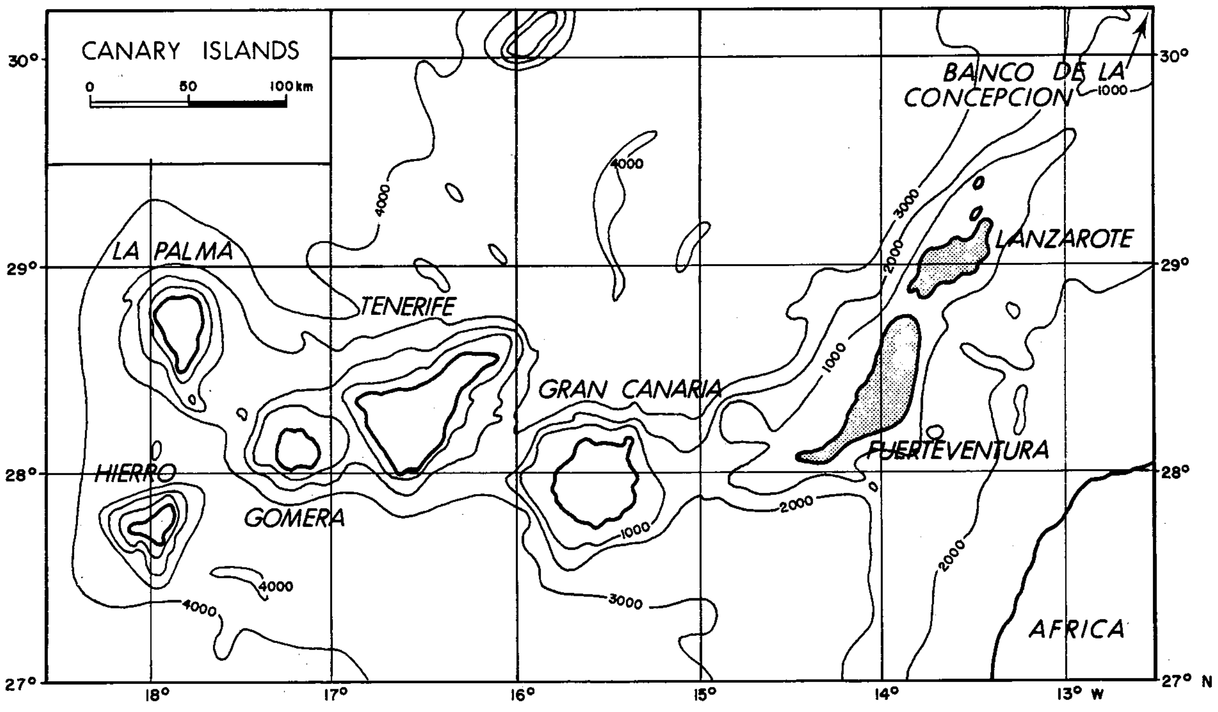

Fig. 1. General topography of the Canary Islands.

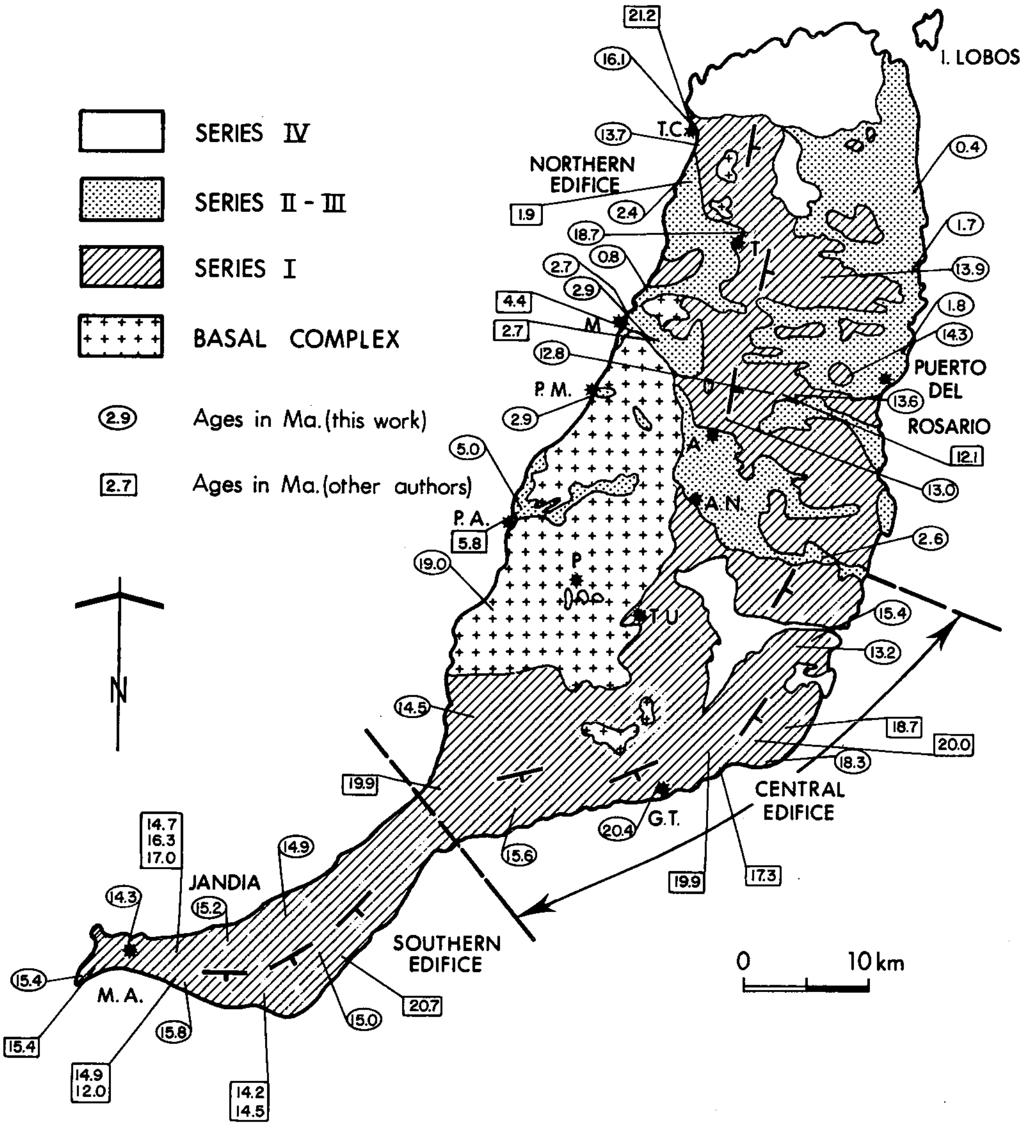

Fig. 2. Schematic geological map of Fuerteventura. Localities mentioned in the text: *A* = Ampuyenta; *AN.* = Antigua; *G.T.* = Gran Tarajal; *M* = Los Molinos; *M.A.* = Montaña Azufra; *P* = Pájara; *P.A.* = Puerto de Ajuy; *P.M.* = Playa de los Mozos; *T* = Tindaya; *T.C.* = Tostón-Cotillo; *TU.* = Tuineje.

two main units: Series I and Series II, III and IV (Fúster et al., 1968a, b). Series I lies unconformably over the basal complex and its base is of Miocene age. The unconformity, therefore, represents a long period of erosion. This series is a tabular succession of lavas and pyroclastics, mainly basaltic with frequent ankaramitic accumulates and trachybasaltic differentiates and very few trachytes (Fúster et al., 1968a, b; Ibarrola, 1969, 1970; Hernández-Pacheco and Ibarrola, 1973; Fúster, 1975). The base of the series is cut by numerous dykes, which represent the feeders of higher levels (López Ruiz, 1969).

Another fairly long erosion period separates the deeply eroded surface of Series I from the Pliocene to Recent Series II, III and IV, constituted exclusively of basaltic volcanoes, normally aligned following fracture lines oblique to the main NNE–SSW trend, and associated lava flows. This activity has continued up to prehistoric (Fuerteventura) or even contemporary times (Lanzarote, where the latest eruption took place in 1824), (Hernández-Pacheco, 1910; Carracedo et al., 1990).

The present work is based on the results of 64 new K–Ar age determinations for the Miocene–Pleistocene volcanic series, performed by J.M. Cantagrel, C. Jamond and E. Ibarrola at Lab. No. 10 of the CNRS—Université B. Pascal in Clermont-Ferrand. These data, together with the 32 formerly published (Abdel-Monem et al., 1971; Meco and Stearns, 1981; Féraud, 1981; Féraud et al., 1985) enable us to describe the evolution of both islands and their relationship with the rest of the archipelago which modifies significantly the models previously proposed. Part of the results discussed here have been advanced in previous short notes by the authors (Ibarrola et al., 1988, 1989b; Casquet et al., 1989).

Methods

The analytical techniques used have been described in detail by Cantagrel (1973) and Cantagrel and Baubron (1983). Whole-rock samples were used, with separation of the olivine or olivine–pyroxene fraction. The size of the particles selected for analysis varied between 0.4 and 1.0 mm. Ar was extracted from sample aliquots of 1–2 g and it was analysed by isotopic dilution by means of a modified MS-10 mass spectrometer. K was determined in duplicate by atomic absorption spectrometry.

K–Ar ages were calculated using the constants of the 1976 international agreement (Steiger and Jaeger, 1977) and errors (at 2σ) were calculated according to the method of Dalrymple and Lanphere (1969). K–Ar ages obtained by former authors were recalculated using the new constants.

Description and K–Ar chronology of the formations

Miocene subaerial volcanism

The dip of the flows in the volcanic sequence on both islands (Figs. 2 and 3) and the considerable erosion they show all around the coast, but specially on the W-NW side, indicate that the original extent of these edifices was considerably greater. The maximum observable thickness at present is 670 m in Famara (Lanzarote) and 800 m in Jandía (Fuerteventura). Thus, the original thickness is likely to have exceeded 1000 m in some cases.

Fuerteventura

Fúster et al. (1968b), on the basis of volcano-stratigraphic criteria, defined three levels or units, lower, middle and upper, within Series I. Later work has indicated that, although roughly valid as a first approximation, that subdivision cannot be applied in a simple way to the whole island. Field evidence, including the radial disposition of dykes and the radial dip of flows, supports the interpretation of Series I as formed by three overlapping, independent edifices (Fig. 2), as shown by Ancochea et al. (1990). The available K–Ar ages (Casquet et al., 1989) for this series are grouped into three chronological units, between 20 and 12 Ma.

The southern edifice corresponds to the peninsula of Jandía (Fig. 2), whose structure suggests that it constituted a large shield with its centre slightly north off the present coast. Fúster et al. (1968b) identified three levels in the volcanic sequence of Jandía, separated by erosional unconformities. Alkaline ankaramitic basalts are the dominant rock type. Some trachytic dykes and plugs cut through the basaltic sequence (Muñoz, 1969; Cubas et al., 1988).

Abdel-Monem et al. (1971) obtained ages of 17.0, 16.3 and 14.7 Ma, for three closely spaced samples from the western part of Jandía. The

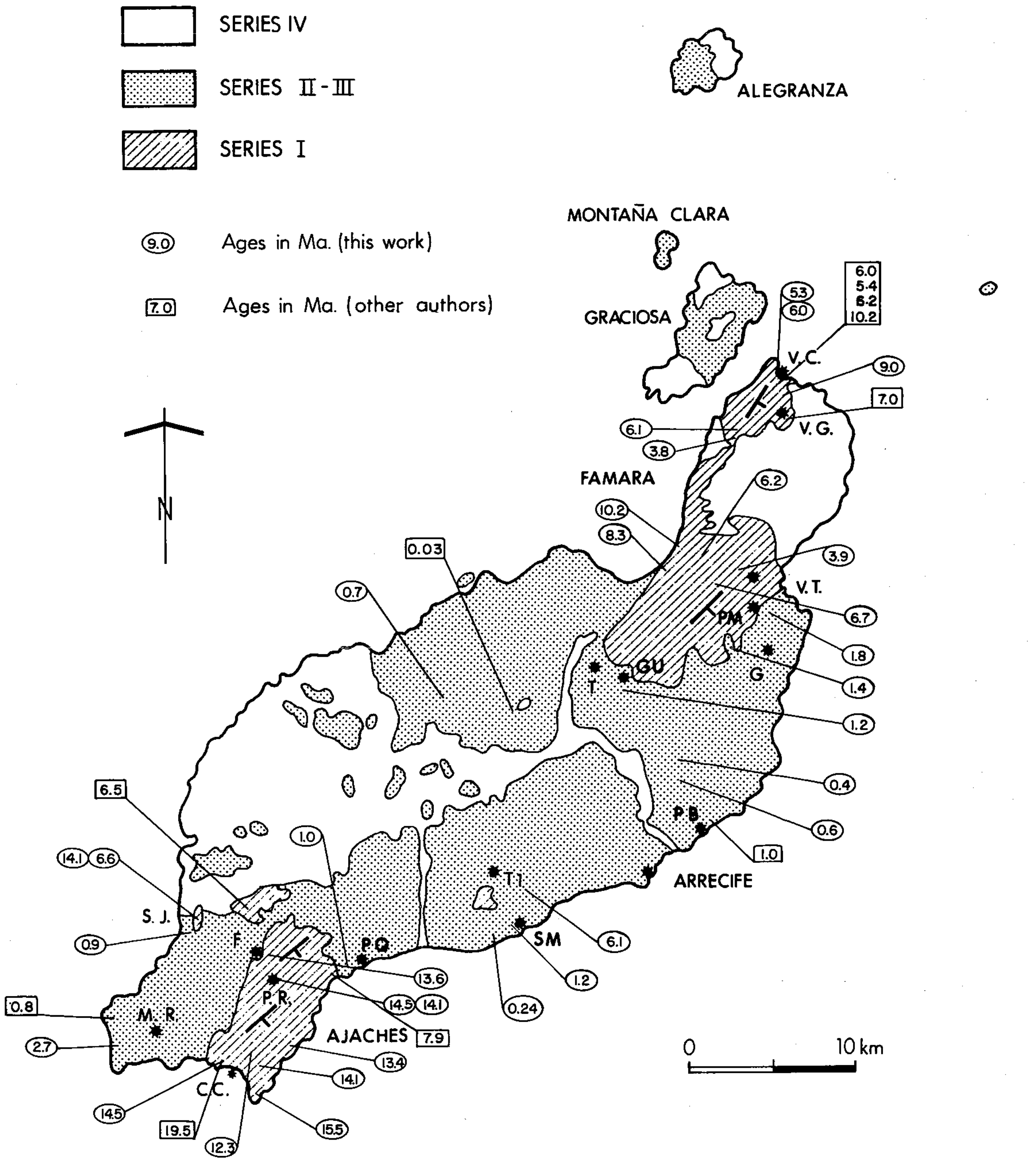

Fig. 3. Schematic geological map of Lanzarote. Localities mentioned in the text: *C.C.* = Castillo de las Coloradas; *F* = Atalaya de Femés; *G* = Guatiza; *GU* = Guanapay; *M.R.* = Montaña Roja; *PB* = Playa Bastian; *PM* = Presa de la Mala; *PQ* = Playa Quemada; *P.R.* = Pico Redondo; *S.J.* = Salinas del Janubio; *SM* = Salinas de Matagorda; *T* = Teguise; *TI* = Tías; *V.C.* = Valle Chico; *V.G.* = Valle Grande; *V.T.* = Valle de Tabayesco.

K–Ar ages we have obtained (Table 1) fall within a much shorter and somewhat younger interval, 15.8 to 14.9 Ma. A trachytic plug has been dated 14.3 Ma. Most of the dykes dated by Féraud (1981) have ages (15.5–14.2 Ma) consistent with our data, but one is considerably older (20.7 Ma) and another younger (12.0 Ma). The latter could represent a late episode in the edifice, and the former could correspond to the feeders of the lower part of the series, for which no samples were suitable for age determination, due to their intense alteration.

The central edifice of Ancochea et al. (1991), formed mainly by basaltic flows with scarce pyroclastics, overlies the basal complex and has a half-circle shape with a central depression. Four levels or units have been identified; the youngest appears only locally and it was erupted after the central depression had formed. Abundant dykes, with a roughly radial pattern (fig. 74 of Fúster et al., 1968b) cut across the two lowest units and, to a lesser extent, the upper ones.

In this edifice we have found most of the oldest K–Ar ages for the subaerial series of Fuerteventura: 19.0 Ma for a dyke cutting through the gabbros of the basal complex, 20.4 and 18.3 Ma for flows in the lower and middle units (Table 1). Four dykes dated by Féraud (1981) in this sector have ages between 20.0 and 17.3 Ma. The two upper units of the succession, with ages of 15.6, 15.4 and 14.5 Ma, seem to have erupted after a fairly long period of inactivity. Finally, a sample from the uppermost unit yielded an age of 13.2 Ma. Thus, this edifice was built during three distinct episodes, one 20.4–17.0 Ma, a second one centred around 15 Ma and a late episode around 13 Ma.

The northern edifice, partly overlapped with the central one, has a lower unit, predominantly of basaltic lavas, over which there is a volcaniclastic formation (lahar, debris-flows,

TABLE 1

K–Ar ages of volcanic rocks of Series I from Fuerteventura

Sample	Rock type	Locality	% K	% Ar_{atm}	$^{40}Ar^*$ (ng/g)	Age (Ma)
Southern edifice (Jandía)						
F-16-C	Aug.–oliv. basalt	Barranco de los Escobones	1.17	49.8	1.29	15.8±0.3
F-19-C	Aug.–oliv. basalt	Punta de Jandía-Faro	0.741	60.3	0.797	15.4±0.4
F-50-AC	Trachyte	S of Casa del Mosquito (dyke)	2.69	10.2	2.85	15.2±0.3
F-76-AC	Basalt	Pico de la Zarza 380 m, southern side	1.09	30.4	1.14	15.0±0.3
F-73-AC	Ankaramite	Pico de la Zarza, southern side	1.60	22.6	1.66	14.9±0.3
F-17-C	Trachyte	Montaña Azufra	3.87	21.2	3.84	14.3±0.3
Central edifice						
F-24-C	Ankaramite	Montaña de Gran Tarajal	0.978	30.4	1.39	20.4±0.4
FV-33-F	Basalt	Tablero de las Estancias	1.48	68.3	1.96	19.0±0.5
F-27-C	Olivine basalt	Faro de la Entallada	1.015	21.9	1.29	18.3±0.3
F-58-AC	Basalt	S of Morro de los Tarajales	2.17	20.7	2.35	15.6±0.3
F-59-AC	Trachybasalt	Atalaya Pozo Negro	1.645	22.4	1.76	15.4±0.3
F-25-C	Aug.–oliv. basalt	Huertas de Chilegua	0.551	66.4	0.553	14.5±0.4
F-60-AC	Picritic basalt	Tablero del Saladillo	0.639	44.8	0.588	13.2±0.3
Northern edifice						
F-1-C	Trachyte	Tindaya	4.07	10.2	5.30	18.7±0.3
F-69-AC	Plagioclase basalt	Tostón-Cotillo	1.09	35.4	1.22	16.1±0.3
F-9-C	Trachybasalt	Punta de la Atalaya	1.37	33.6	1.36	14.3±0.3
F-71-AC	Aug.–oliv. basalt	SE of Morro Carnero	1.13	34.9	1.09	13.9±0.3
FV-49-F	Plag. basalt	Tostón-Cotillo	1.08	60.6	1.03	13.7±0.8
F-20-C	Plag. basalt	Montaña de Enmedio	1.494	37.1	1.42	13.6±0.3
F-30-C	Trachybasalt	Montaña del Campo	1.20	54.8	1.08	13.0±0.3
F-52-AC	Plag.–aug. basalt	Pico de la Muda	1.63	32.0	1.48	13.0±0.2
F-21-C	Basalt	Morro de la Galera	1.27	62.0	1.13	12.8±0.3

sediments) up to 200 m thick, called "Formación Ampuyenta" (Fúster et al., 1968b), similar to others described in Tenerife (Ancochea et al., 1990) and La Gomera (Bravo, 1964; Cendrero, 1969; Cantagrel et al., 1984). An upper unit of basaltic lavas lies over this volcaniclastic formation.

Some trachytic domes cut through the lower part of the series, in the western side of the edifice. A sample from one of these (Montaña Tindaya) has yielded 18.7 Ma, but this age must be taken with caution, as the rock shows signs of secondary hydrothermal alteration.

The lowest levels of the edifice appear on the west coast, near Tostón-Cotillo. In this section Abdel-Monem et al. (1971) obtained a K–Ar age of 21.2 Ma. Compared with other determinations, this one appears to be too old; in fact, it is the oldest in Fuerteventura with the exception of the basal complex. In the same sector and in the same point where Abdel-Monem et al. (1971, p. 518) took their sample, we have obtained (Table 1) 16.1 Ma for one of the lowest flows and 13.7 Ma for a higher flow, over an unconformity with sedimentary deposits. Other ages obtained in this edifice are grouped mainly between 14.3 and 12.8 Ma (Table 1). The age of 12.2 Ma published by Abdel-Monem et al. (1971) must be considered with caution, as, according to those authors, it corresponds to a basalt with many amygdules. We have obtained an age of 13.6 Ma for the same stratigraphic level.

The volcaniclastic episode represented by the "Formación Ampuyenta" can be dated between 13.7 (age of sample F-20-C, taken from the flows just below it) and 13.0 Ma (for sample F-30-C, obtained just above).

Lanzarote

Lanzarote is practically a part of the same "island edifice" as Fuerteventura (Fig. 1), as the depth in the narrow strait between the two islands does not exceed 40 m.

Series I of Fúster et al. (1968a) forms here two large eroded edifices, Ajaches in the south and Famara in the north, where the tabular succession of flows and pyroclastics is over 500 m thick, and a few small outcrops surrounded by younger volcanic materials (Fig. 3). Unconformities with palaeosols, indicative of gaps in volcanic activity and erosion, are more frequent here than in Fuertenventura. The general structure of the two edifices suggests that in both cases the eruptive centres were somewhere west of the present outcrops.

In a preliminary note by some of the present authors (Ibarrola et al., 1988), the results of 21 K–Ar determinations for Series I in this island have been reported briefly. These new data, together with the ones published by Abdel-Monem et al. (1971) are discussed here.

The Ajaches edifice, with a maximum altitude of 560 m, is formed by a succession of lavas and pyroclastics, dipping gently towards the ESE. A marine abrasion surface cuts the edifice in the S and SW, with beach deposits up to an altitude of 55–60 m (Driscoll et al., 1965), considered as Early Pliocene by Meco and Stearns (1981). This surface also appears in the western part of the massif, but covered by younger flows. The lower part of the edifice has some ankaramitic plugs and laccoliths, as well as trachytic plugs and dykes.

Table 2 contains the results of K–Ar determinations carried out by us. Most data are grouped between 15.5 and 14.1 Ma, which seems to have been the main period of activity. At the upper part of the edifice ages are around 14 Ma; in particular, a sample taken in Pico Redondo, at 260 m, yielded 14.5 Ma and one in the same locality, at 500 m, 14.1 Ma. A very obvious unconformity, with a well-developed palaeosol, occurs between these elevations. Ages of 13.6 Ma and lower have been obtained for samples from the fringe of the edifice. These have been interpreted by Ibarrola et al. (1988) as due to eruptions occurring after an erosion period between 14.1 and 13.6 Ma. The age of 19.5 Ma obtained by Abdel-Monem et al. (1971) for a basalt in the Castillo de las Coloradas appears far too old, since we have obtained 14.5 Ma in the same locality and only 15.5 Ma from lower levels.

North and west of the Ajaches, in the lower parts of the island, several small outcrops of Series I occur (Fig. 3). The most interesting of these, in the Salinas del Janubio, is represented in Figure 4. The lower part of the succession, for which a K–Ar age of 14.1 Ma has been obtained, is equivalent to the Ajaches and it represents the eroded remnants of the same edifice, as suggested by Driscoll et al. (1965). The age of the marine abrasion platform covered by fossil-bearing calcarenites, for which Cendrero et al. (1967a) proposed a Miocene, probably Burdigalian age, is illustrated in Figure 4.

The 6.1 Ma determination from south of Tias and two by Abdel-Monem et al. (1971), 6.6 and 7.9 Ma, also seem to correspond to this Late Miocene period of activity. Similar ages, as discussed below, are common in the Famara edifice. Thus, the fairly intense activity which was taking place at that time in the north of the island also extended southwards, over the eroded remnants of the Ajaches massif (Ibarrola et al., 1988).

The northern edifice, Famara, is over 600 m high and its layers of lavas and pyroclastics also dip gently towards the ESE (Fig. 3). The base of the succession which can be observed at the scarp on the western side of the edifice has been dated as 10.2 Ma, and an age of 8.3 Ma has been obtained for a flow 120 m above sea level (Table 2). A basaltic laccolith in the northeastern part of the massif yielded 9.0 Ma. The calcarenitic layer described by Rothe (1966) as Tortonian in the northern part of the massif, appears to be Messinian, as flows below and

TABLE 2

K–Ar ages of volcanic rocks of Series I from Fuerteventura

Sample	Rock type	Locality	% K	% Ar_{atm}	$^{40}Ar^*$ (ng/g)	Age (Ma)
Ajaches edifice						
L-50-F	Basalt	Punta Papagayo	1.07	39.4	1.155	15.5 ±0.3
L-7-F	Basalt	Castillo de las Coloradas	0.748	64.3	0.754	14.5 ±0.4
L-16-F	Trachyte	Pico Redondo, 260 m	1.125	44.9	1.131	14.5 ±0.3
L-10-F	KF from trachyte	Rubicón, N of Papagayo	2.77	40.0	2.724	14.1 ±0.3
L-19-F	Trachybasalt	Pico Redodndo, 500 m	1.58	49.3	1.550	14.1 ±0.3
L-14-F	Basalt	S of Atalaya de Fermés	0.477	71.4	0.451	13.6 ±0.4
L-15-F	Basalt	W of Ajaches, S of Hacha Chica	0.880	59.6	0.818	13.4 ±0.3
L-9-F	Basalt	N of Punta Papagayo	1.655	51.2	1.42	12.3 ±0.3
Other outcrops in the south						
L-4-F	Trachybasalt	Salinas del Janubio, base of Series I	1.45	49.3	1.426	14.1 ±0.4
L-5-F	Ankaramite	Salinas del Janubio, top of Series I	0.924	80.0	0.426	6.7 ±0.29
L-12-F	Ankaramite	Tias, Cantera de las Majadas	0.736	84.1	0.310	6.1 ±0.3
Famara edifice						
L-24-F	Basalt	W of Famara, 4th Galeria, 0 m	0.754	77.7	0.536	10.2 ±0.4
L-2-F	Ne-Ankaramite	Lomo del Zalahar, 50 m	0.679	88.8	0.427	9.0 ±0.3
L-25-F	Ankaramite	W of Famara, 2th Galeria, 100 m	0.544	92.9	0.427	8.3 ±1.0
L-35-F	Ankaramite	Peña Pequeña	0.970	60.3	0.449	6.7 ±0.2
L-33-F	Olivine basalt	C. del Norte, km 24	0.600	82.6	0.257	6.2 ±0.3
L-45-F	Ankaramite	Famara scarp, 340 m	0.853	82.1	0.360	6.1 ±0.3
L-44-F	• Basanite	Orzola, 0 m (Valle Chico)	0.817	85.8	0.339	6.0 ±0.4
L-1-F	• Ankaramite	Orzola, 20 m (Valle Chico)	0.712	84.2	0.264	5.3 ±0.3
L-31-F	Olivine basalt	Km 3, road to Tabayesco	0.870	85.4	0.236	3.66±0.27
L-46-F	Ankaramite	Famara scarp (370 m)	1.24	80.4	0.324	3.9 ±0.15

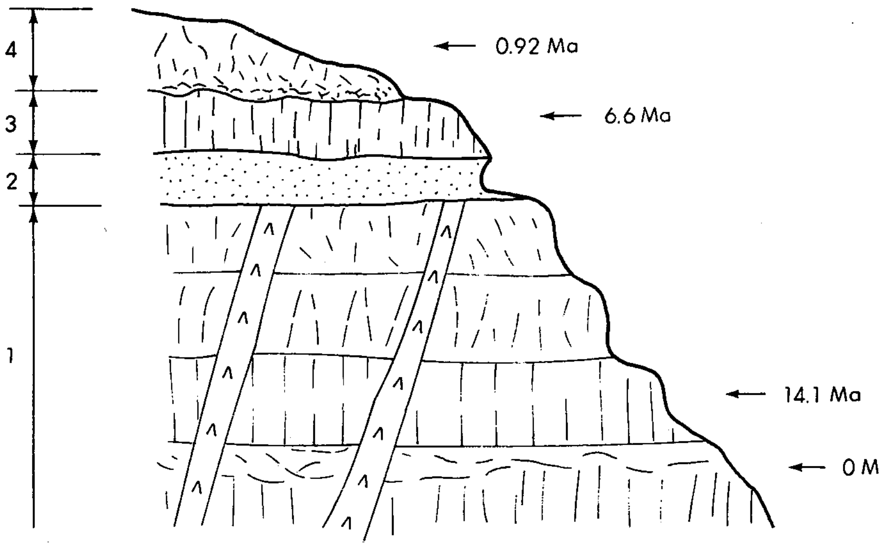

Fig. 4. Schematic section (not to scale) of the succession in the Salinas del Janubio. *1*=Series I corresponding to the Ajaches edifice; *2*=Miocene calcarenites; *3*=Series I corresponding to the Famara edifice; *4*=basaltic flow of Series III (after Ibarrola et al., 1988).

above it have been dated at 6.0 and 5.3 Ma, respectively. The age of 10.3±2 Ma obtained for the former flow by Abdel-Monem et al. (1971), which is actually an "average" of six determinations carried out on samples from two different points, should not be considered as reliable, as indicated by those authors who state that the ages from this area "are thus somewhat uncertain" (p. 499) and that their data "give results whose reproducibility is rather poor" (p. 500).

The rest of the ages from Famara are grouped into two periods, one around 6 Ma (five ages obtained by us, plus four by Abdel-Monem et al., 1971) and another around 3.9–3.8 Ma. A flow in the upper part of the Famara scarp, at 340 m altitude, yielded a 6.1 Ma age and one above it, at 370 m, 3.8 Ma. Between both flows a very clear unconformity with a palaeosol occurs.

So, the Famara edifice was built during three periods of activity, 10.2–8.3, 7.2–5.3 and 3.9–3.8 Ma, separated by erosive periods. However, this edifice is very complex and more data would be needed to define more precisely its volcano-stratigraphy.

The picture that emerges from the data above shows a volcanic edifice being built in the southern part of Lanzarote between 15.5 and 12.3 Ma. A period of relative volcanic quiescence and erosion took place between 12.3 and 10.2 Ma, when the Famara edifice started its activity. In Famara several pulses of activity took place, the main one occurring around 6 Ma and reaching also the southern part, over the eroded remnants of the Ajaches massif.

Post-Miocene activity

An important temporal gap, greater in Fuerteventura than in Lanzarote, separates the Miocene series from the Pliocene–Quaternary activity. During that period of quiescence the Miocene edifices were deeply eroded, losing a large part of their original volume, as indicated by the missing volumes in the "valleys" between the existing remnants of Series I.

The new cycle of activity consisted of scattered groups of small volcanoes and associated lava fields. These volcanoes were normally aligned along NE to ENE directions in Lanzarote but follow different directions in Fuerteventura.

A relative chronology (Series II, III and IV) was established for these volcanoes by Fúster et al. (1968a, b) on the basis of their relative positions with respect to elevated marine abrasion surfaces and deposits—considered as Quaternary (Tinkler, 1966; Lecointre et al., 1967)—and of geomorphological features indicative of degree of erosion. Of course, the value of this relative chronology is limited, especially considering that the altitude of marine abrasion surfaces is not a very reliable age indicator, as it might have been influenced by tectonic and volcanic movements (Lietz and Schmincke, 1975).

Fuerteventura

The post-Miocene volcanic activity in this island occurred in the central and northern parts (Fig. 2). Ten new K–Ar ages (Table 3) have been obtained for these series, to which the ones published by Abdel-Monem et al. (1971) and Meco and Stearns (1981) can be added. The first period of activity is represented by the volcano of Betancuria (Fig. 2), whose flows reached the coast, over a wave-cut platform, along a 5-km front. The relationships between these flows and other units are shown in Figure 5. We have obtained for the flows of that volcano an age of 5.0±0.3 Ma, analytically overlapping the 5.8±0.5 Ma obtained by Meco and Stearns (1981). As the sands at the base of these flows are mixed with palagonitic hyaloclastites and show deformation structures and penetration by volcanic material, it can be concluded that they were not consolidated when the lavas were emplaced. Thus, the abrasion platform and coastal sands are contemporaneous with the flows, that is, Lower Pliocene.

Several samples from flows above the alluvial sediments which overlie the lavas just described (Fig. 5), have yielded ages below 3 Ma (2.9, 2.8, 2.7 Ma, Table 3; 2.7 Ma in Meco and Stearns, 1981), thus bracketing the age of these sediments between 5.0 and 2.9 Ma, that is, Early Pliocene. The age of 4.4 Ma published by Abdel-Monem et al. (1971) for a sample from Los Molinos must be considered with caution. Judging from the description given by those authors, this sample was taken from a position equivalent to our sample 491-5, for which we obtained an age of 2.7 Ma (Table 3); our sample F-11-C, dated as 2.9 Ma (Table 3), was taken from a lower flow. The age of 2.7 Ma ob-

TABLE 3

K–Ar ages of volcanic rocks from the post-Miocene Series of Fuerteventura

Sample	Rock type	Locality	% K	% Ar_{atm}	$^{40}Ar^*$ (ng/g)	Age (Ma)
488-4	Oliv. basalt	Barranco de Ajuí	0.734	65.9	0.253	5.0 ±0.3
F-11-C	Oliv. basalt	Barranco de Los Molinos	1.00	88.3	0.201	2.9 ±0.2
491-5	Oliv. basalt	Puerto de Los Molinos	1.03	69.9	0.191	2.7 ±0.2
F-67-AC	Oliv. nephelinite	Tablero de Golfete	0.461	89.3	0.091	2.85±0.25
F-8-C	Basanite	Barranco de Antigua	0.468	87.6	0.086	2.6 ±0.2
492-6	Basalt	Aljibe de la Cueva, Tostón-Cotillo	0.951	84.2	0.155	2.4 ±0.4
487-3	Basanite	Barranco de la Herradura	1.01	89.8	0.129	1.8 ±0.5
485-1	Oliv. basalt	El Veril de Santiago	1.06	83.4	0.128	1.7 ±0.3
F-68-AC	Oliv. basalt	Barranco de Jarubio	1.13	91.1	0.065	0.83±0.09
486-2	Oliv. basalt	La Salina	0.986	92.5	0.03	0.4 ±0.1

tained by Meco and Stearns (1981) in the Barranco de la Cruz corresponds to the same succession of flows.

Further north, near Tostón-Cotillo, a flow overlying the Lower Pliocene beach deposits yielded 2.45 Ma. The age of 1.88 Ma published by Abdel-Monem et al. (1971) for a sample taken a bit further south from this one could correspond to a higher level of Series II.

The volcanoes which erupted towards the eastern side of the island tend to be younger. A flow in the Barranco de Antigua, with an age 2.6 Ma, is comparable to the ones just described and it corresponds to the intermediate period of Series II (Ibarrola et al., 1989b). Other determinations for lavas on the eastern side, north of Puerto del Rosario, have yielded 1.8 and 1.7 Ma. They correspond to the upper period of Series II described by Ibarrola et al. (1989b).

Data for Series III are scarce, as the K–Ar method is not very precise for samples with low K content and dates in the range of 10^5 years. However, the 0.8 and 0.4 Ma ages obtained show that volcanic activity continued during the Pleistocene.

For Series IV of Fúster et al. (1968b) two absolute age determinations are available, one ^{14}C age lower than 35,000 years from a volcano near Tuineje (Meco and Pomel, 1985) and a thermoluminescence age of 51,000 years for the volcano of Pájara (Pomel et al., 1985).

These data show that Series II of Fúster et al. (1968b) was formed during three periods of activity (Ibarrola et al., 1989b), one in the Lower Pliocene, a second one in the Upper Pliocene and the third in the Pliocene–Pleistocene transition. Series III, for which there are few determinations, is Pleistocene and Series IV is Upper Pleistocene to Holocene.

Lanzarote

The oldest K–Ar age for the post-Miocene materials, 2.7 Ma, has been obtained in the la-

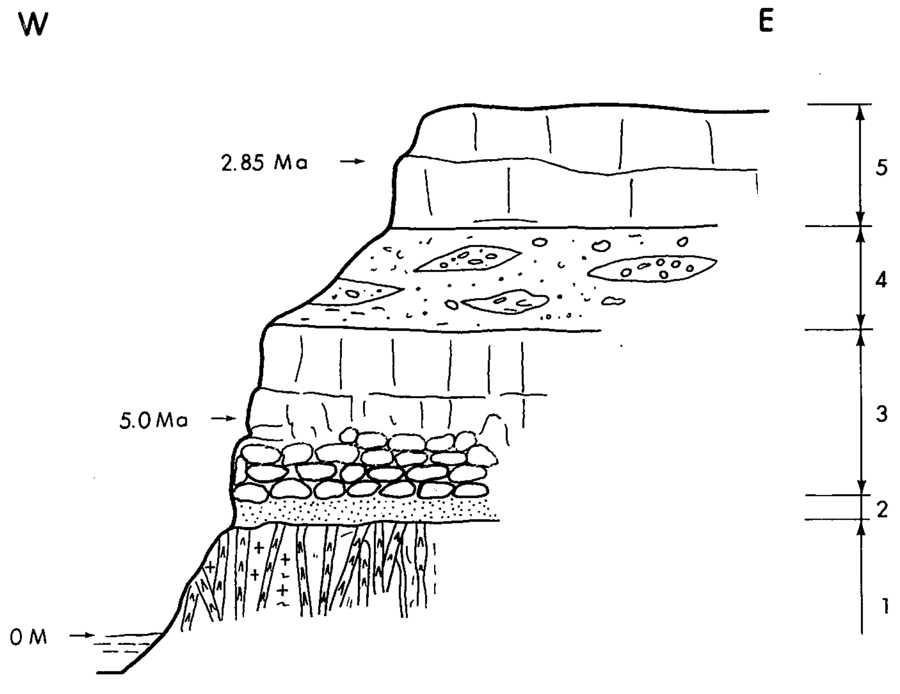

Fig. 5. Schematic section (not to scale) showing the chronostratigraphic relationships between Series II and other formations in the western part of Fuerteventura. *1* = basal complex; *2* = fossil Pliocene beach; *3* = flows from the volcano of Betancuria (Series II-A); *4* = alluvial sediments; *5* = flows from Montaña Tirafe (Series II-B).

vas of Montaña Roja (Fig. 3; Table 4), included by Fúster et al. (1968a) in Series II-A. For the same volcano Meco and Stearns (1981) obtained 0.82 Ma. We feel that this is too recent, because the lavas of the Atalaya de Femés, which cover those of Montaña Roja, have yielded 0.92 Ma. Moreover, between the eruption of the Montaña Roja and Atalaya de Femés lavas a fairly long period must have elapsed, as the former materials developed thick carbonate crusts and were eroded and covered by raised beaches at 20 and 10 m (Tinkler, 1966; Fúster et al., 1968a). In the neighbouring area, to the north, over the Atalaya de Femés lavas, the carbonate crusts are thin and only the 10 m beach occurs. These data, together with the fact that the 20 m beach in Fuerteventura appears below flows dated 2.4 Ma, suggest an Upper Pliocene rather than Pleistocene age for this beach. Even though the 2.7 Ma age might appear to be old for Lanzarote, it is equivalent to the ages obtained for Series II volcanoes on the west coast of Fuerteventura.

The lavas in the Presa de la Mala and the ones north of Guatiza, mapped by Fúster et al. (1968a) as Series II-A, have, respectively, 1.8 and 1.4 Ma (Table 4); that is, Pliocene–Pleistocene and Early Pleistocene.

There is a group of ages around 1 Ma, those of Salinas de Matagorda (1.2 Ma), Guanapay (1.2 Ma), north of Playa Quemada (0.99 Ma) and the ones at the top of the sequence in the Salinas del Janubio (0.92 Ma; Fig. 4), which come from the Atalaya de Femés. The age of 0.99 Ma obtained by Abdel-Monem et al. (1971) in Playa Bastian also belongs to this group. In the map of Fúster et al. (1968a), all these flows appear as Series II-B, except the Atalaya de Femés, represented as Series III. Finally, there is a more recent group of ages, between 0.73 and 0.24 Ma (Table 4), to which the 0.03 Ma age obtained by Abdel-Monem et al. (1971), can be added. They correspond essentially to edifices assigned to Series III by Fúster et al. (1968a).

The relationships between Series II-B and III and the 20 m beach can be observed south of Arrecife. Here, the lavas dated as 1.2 Ma are covered by a fossil beach with *Strombus bubonius* (Lecointre et al., 1967; Cendrero et al., 1967a; Meco and Stearns, 1981) and this, in turn, by flows from the volcanoes near Tias, assigned to Series III, for which a 0.24 Ma age has been obtained.

Series IV is represented by prehistoric and historical eruptions, the latter from 1730 to 1736 and 1824. We have, then, a fairly continuous Pliocene–Recent activity in Lanzarote, with a maximum in the lower Pleistocene.

TABLE 4

K–Ar ages of volcanic rocks from the post-Miocene Series of Fuerteventura

Sample	Rock type	Locality	% K	% Ar_{atm}	$^{40}Ar^*$ (ng/g)	Age (Ma)
L-23-F	Basalt	Montaña Roja	1.025	95.6	0.189	2.7 ±0.6
L-51-F	Oliv. basalt	Presa de Mala	0.497	94.5	0.062	1.8 ±0.3
L-43-F	Oliv. basalt	Montaña Temeje-Guatiza	0.963	83.0	0.094	1.41±0.08
L-48-F	Oliv. basalt	Salinas de Matagorda, Punta Lima	0.81	90.1	0.066	1.2 ±0.1
L-39-F	Basalt	Guanapay, Meseta de la Torre	0.561	95.2	0.0465	1.20±0.24
L-38-F	Oliv. basalt	N of Playa Quemada	0.995	95.0	0.068	0.99±0.20
L-6-F	Ankaramite	Salinas del Janubio	0.574	96.8	0.0365	0.92±0.3
L-47-F	Ankaramite	Tinajo-Morro de San Roque	0.872	92.2	0.044	0.73±0.1
L-42-F	Trachybasalt	Tahiche	0.905	91.6	0.039	0.63±0.07
L-41-F	Trachybasalt	NE of Tahiche	0.930	94.7	0.023	0.35±0.06
L-49-F	Basalt	Playa de los Pocillos	0.668	98.3	0.011	0.24±0.14

Discussion

Temporal and spatial distribution of volcanic activity

The data presented above show that subaerial volcanic activity has been almost continuous in Lanzarote and Fuerteventura during the last twenty million years. If the submarine materials of the basal complex are considered, volcanic activity extends to the Paleocene–Oligocene (Ibarrola et al., 1989a) or perhaps even the Albian (Le Bas et al., 1986); nevertheless, this point remains to be defined more precisely. Therefore, these islands are part of a sector of the lithosphere where the thermal and dynamic anomalies which lead to the production and ascent of alkaline basaltic magmas have persisted for an exceptionally long period.

The K–Ar ages presented here show that, after a long period of erosion which affected the basal complex, subaerial volcanic activity took place during two distinct cycles: one mostly Miocene, corresponding to Series I of Fúster et al. (1968a, b) and a Pliocene–Recent cycle including Series II, III and IV of the same authors. The first one produced large shield volcanoes and tabular successions of lavas and pyroclastics, whereas during the second cycle small scattered volcanoes were formed. A period of volcanic repose, longer in Fuerteventura than in Lanzarote and during which the Series I edifices were deeply eroded, occurred between both cycles.

The edifices of Series I do not correspond to the frequent model in oceanic islands, with a short and intense period of activity. Each edifice has been active during several million years, in some cases more than six (Fig. 6; Table 5), with pulses in the activity and gaps represented by unconformities with palaeosols, sediments or volcaniclastic materials.

Although the possibility of the existence of older materials at the base of the sequence cannot be totally excluded, and there is no control of the materials which might have disappeared by erosion at the top, it appears that each edifice had its own separate evolution. In Jandía (Fig. 6), maximum activity occurred between 16 and 14 Ma, when all the flows dated by us and most of the dykes dated by Féraud (1981) were formed (some activity could have taken place between 20 and 17 Ma, but more data are necessary to define this). The central edifice of Fuerteventura had an initial phase of activity in the period 20–17 Ma, followed by two others between 16 and 13 Ma. The northern edifice had its main activity between 14 and 12 Ma. In Lanzarote, the Ajaches volcano was built also during the Middle Miocene, 16–12 Ma. The Famara edifice is different, as it started in the Upper Miocene and continued well into the Pliocene, 10–4 Ma.

In conclusion, there is a general similarity among the Ajaches, in Lanzarote, and the three edifices of Fuerteventura. All of them were active during the period 16–13 Ma, that is, the Middle Miocene. Only the central edifice has well-documented activity extending to 20 Ma, but it is possible that the altered, undated materials at the base of Jandía might have a similar age, as suggested by the dates obtained by Féraud (1981). Famara, on the other hand, formed when the activity in the other edifices was over and they had already suffered very considerable erosion.

So, Series I of Fúster et al. (1968a, b), although it includes edifices with very clear similarities from the geological, volcanological, petrological and geochemical point of view, does not represent a chronological unit. The kind of sequence observed in these volcanic edifices (fissural eruptions, erosion, multi-vent volcanism) has taken place repeatedly in the eastern ridge of the Canaries, at different periods and locations.

The gap in activity between the Miocene and post-Miocene volcanic cycles (Fig. 6) also varied. In Fuerteventura and Ajaches there is a general lack of eruptions between 12 and 8 Ma. In the case of Jandía no activity younger than 12 Ma has been recorded. In the central

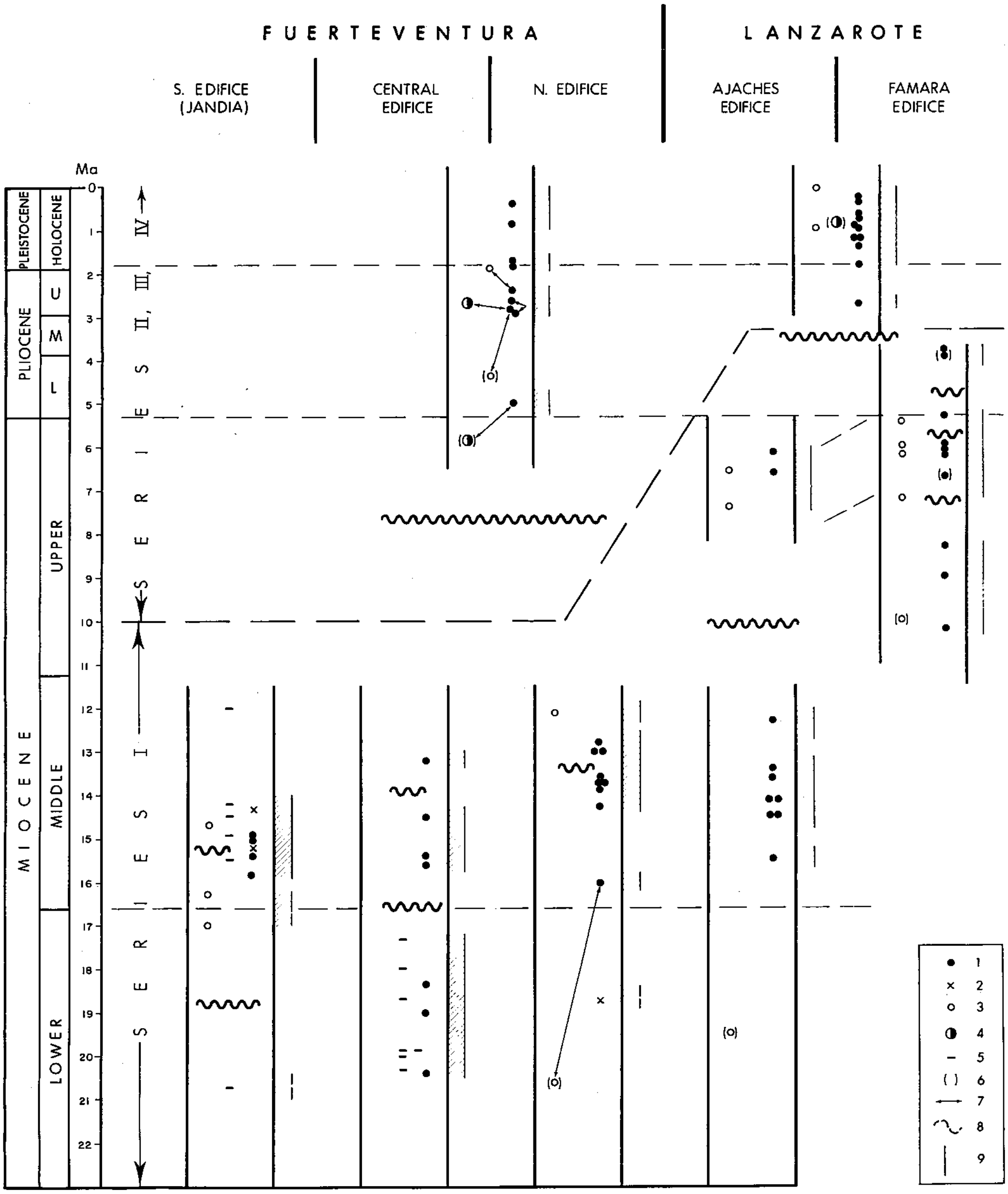

Fig. 6. Temporal and spatial distribution of age determinations in Fuerteventura and Lanzarote. *1*=basaltic rocks (s.l.), this work; *2*=salic rocks, this work; *3*=Abdel-Monem et al., 1971; *4*=Meco and Stearns, 1981; *5*=Féraud, 1981; *6*=uncertain determination; *7*=determinations corresponding to the same unit; *8*=unconformity; *9*=period with volcanic activity.

and northern edifices of Fuerteventura the latest episodes (Ancochea et al., 1990) are not well defined and they could extend beyond the 12.1 Ma so far determined. In this sector the activity started again around 5 Ma, with the post-Miocene eruptions. The gaps in Ajaches took place between 12.3 and 8 Ma and between 6.1 and 2.7 Ma, whereas in Famara it appears between 3.8 and 1.8 Ma. Thus, the data so far available indicate that there is a certain SSW–NNE polarity in the development of volcanism in Fuerteventura–Lanzarote, both in

TABLE 5

Well-recorded period of activity in volcanic edifices of Series I

	Oldest age (Ma)	Youngest age (Ma)	Minimum interval (Ma)
Fuerteventura			
Southern edifice (Jandía)	17.0	14.2	2.8
Central edifice	20.4	13.2	7.2
Northern edifice	16.0	12.1	3.9
Lanzarote			
Ajaches edifice	15.5	12.3	3.2
Famara edifice	10.2	3.8	6.3

the first cycle (Series I) and in the beginning of the second one (Series II, III and IV).

Eruptive rates

Eruptive rates have been estimated considering the minimum size of the different edifices and the well-documented time span during which they were constructed. The minimum size of the different massifs was estimated through the construction of topographic profiles (Fig. 7) and identifying points which could correspond to the original surface of the volcanic edifice. These points were the present topographic maxima and the -80 m isobath, which normally marks the slope break between the Pleistocene–Holocene marine abrasion platform and the non-eroded areas which remained below sea level throughout that period. The maximum size was estimated after the maximum present topographic gradient following the elongated crests of Series I, assuming that this slope continued from the -80 m isobath upwards (Fig. 7). As it can be seen in the figure, the position of the flows indicates that the original gradient of the edifice was lower. The size thus estimated does not normally exceed a 50% increase, which has been taken as the upper limit for all edifices. Logically, the original volume—at the time the highest units presently observable were erupted—must have been somewhere between those two figures. These estimates coincide with the ones presented by Javoy et al. (1986) who, on the basis of oxygen isotopes, estimate that Miocene volcanic structures such as the Jandía volcanic edifice must have had altitudes close to the present one at c. 15 Ma. In the case of the central and northern edifices of Fuerteventura the volume occupied by the basal complex was deducted. This complex includes dykes and intrusives which are, in part, contemporaneous with the subaerial volcanic series, but their volume is difficult to estimate and it does not appear to represent an important proportion of the total volume. In all cases volume calculations refer to the part of the edifices above the present sea level. In the case of Series II, III and IV, average thicknesses of 20–50 m were used for the estimate in Fuerteventura and 50–100 m in Lanzarote. Table 6 summarizes the results obtained.

The data available show that Series I edifices in Fuerteventura were erupted at rates between 0.025 and 0.106 km^3/ka and between 0.01 and 0.02 km^3/ka in Lanzarote, somewhat smaller but comparable to the ones obtained for similar edifices in Tenerife, where Ancochea et al. (1990) have obtained 0.25–0.5

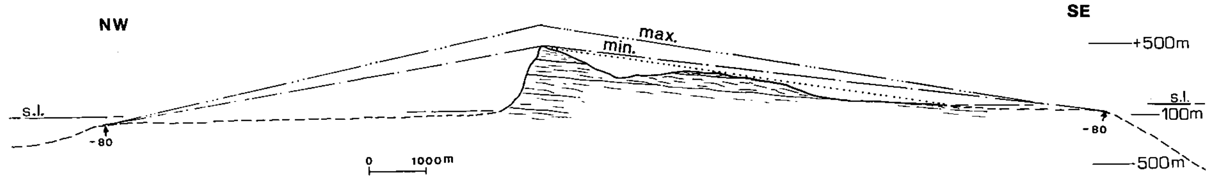

Fig. 7. Topographic profile along one of the crests of Series I in Famara, Lanzarote, showing the break at the -80 isobath, corresponding to the edge of the marine abrasion platform, and the maximum and minimum profiles estimated for the original edifice.

TABLE 6

Size and eruptive rates in the different edifices

Edifice	Volume (km^3)		Time span (Ma)	Eruptive rates (km^3/ka)	
	min	max		min	max
Jandía	76	106	1	0.076	0.106
F. Central	180	276	7.2	0.025	0.038
F. North	181	270	3.3	0.054	0.081
Ajaches	44	66	3.2	0.013	0.020
Famara	64	96	6.4	0.010	0.015
Fuerteventura			5[a]		
II, III, IV	9	22	2.9	0.003	0.007
Lanzarote II, III, IV	37	74	2.7	0.013	0.027

[a]The single episode represented by the 5 Ma old Betancuria volcano has not been considered for the lower figures.

km^3/ka for the ensemble of the three edifices present; that is about 0.1 km^3/ka per edifice. In La Gomera (Cantagrel et al., 1984) the rates obtained vary between 0.05 and 0.3 km^3/ka. The rates proposed by McDougall and Schmincke (1976), Schmincke (1981) and Bogaard et al. (1988) for Gran Canaria are much greater for the "shield-building phase" (2–10 km^3/ka).

In the case of post-Miocene activity, the situation is different, with much higher rates in Lanzarote, 0.013–0.027 km^3/ka, than in Fuerteventura, 0.003–0.007 km^3/ka. These rates are considerably smaller than the ones in Gran Canaria, 0.2 km^3/ka for the second cycle of activity, according to McDougall and Schmincke (1976), and even more so than those of Tenerife, 0.25–1.25 km^3/ka, after Ancochea et al. (1990).

The volume of the island edifices from the 2000 m isobath, approximately 20,000 km^3, considering an eruptive rate equivalent to the maximum rate obtained for the subaerial series (in Jandía), would have taken about 167 Ma to be constructed. This is an unreasonable figure, which, despite the uncertainties inherent to the estimations above, indicates that the rates of magma output must have been higher during the submarine stages of the construction of the ridge.

So, it appears that there was a general decrease in eruptive rates from the initial stages of the formation of the ridge to recent times. This kind of temporal decrease in activity did not take place in La Gomera (Cantagrel et al., 1984) or Tenerife (Ancochea et al., 1990), but also occurred in Gran Canaria (McDougall and Schmincke, 1976; Schmincke, 1981; Bogaard et al., 1988).

Eastern ridge versus central islands

The general temporal development of Lanzarote and Fuerteventura is quite different from the one in the central islands of the archipelago (Fig. 8). In Gran Canaria, the nearest one, Series I of Fúster et al. (1968c) was dated by Abdel-Monem et al. (1971) between 16.6 and 10.5 Ma. However, McDougall and Schmincke (1976), Schmincke (1981) and Bogaard et al. (1988), with new data, indicated that most of this series was erupted in a very short and intense "shield-building phase", less than 0.7 m.y. Tenerife has three independent edifices of Series I, none of which has well-documented activity older than 10 Ma, with the main period of activity between 7 and 5 Ma (Ancochea et al., 1990). La Gomera is a shield volcano with three distinct eruptive periods, 12–10, 8–6 and 5–4 Ma (Cantagrel et al., 1984). Although not very well defined, there seems to be a general migration of activity towards the west (Anguita and Hernán, 1975).

Concerning Lanzarote and Fuerteventura, we can come to the conclusion that Series I of Fúster et al. (1968a, b) does not represent a well defined chronological unit but an alignment of several main edifices with different ages. In fact, taking into account the available data, there is a SSW–NNE polarity in the volcanic activity along the eastern ridge, inferred from the youngest ages known, and the peak in

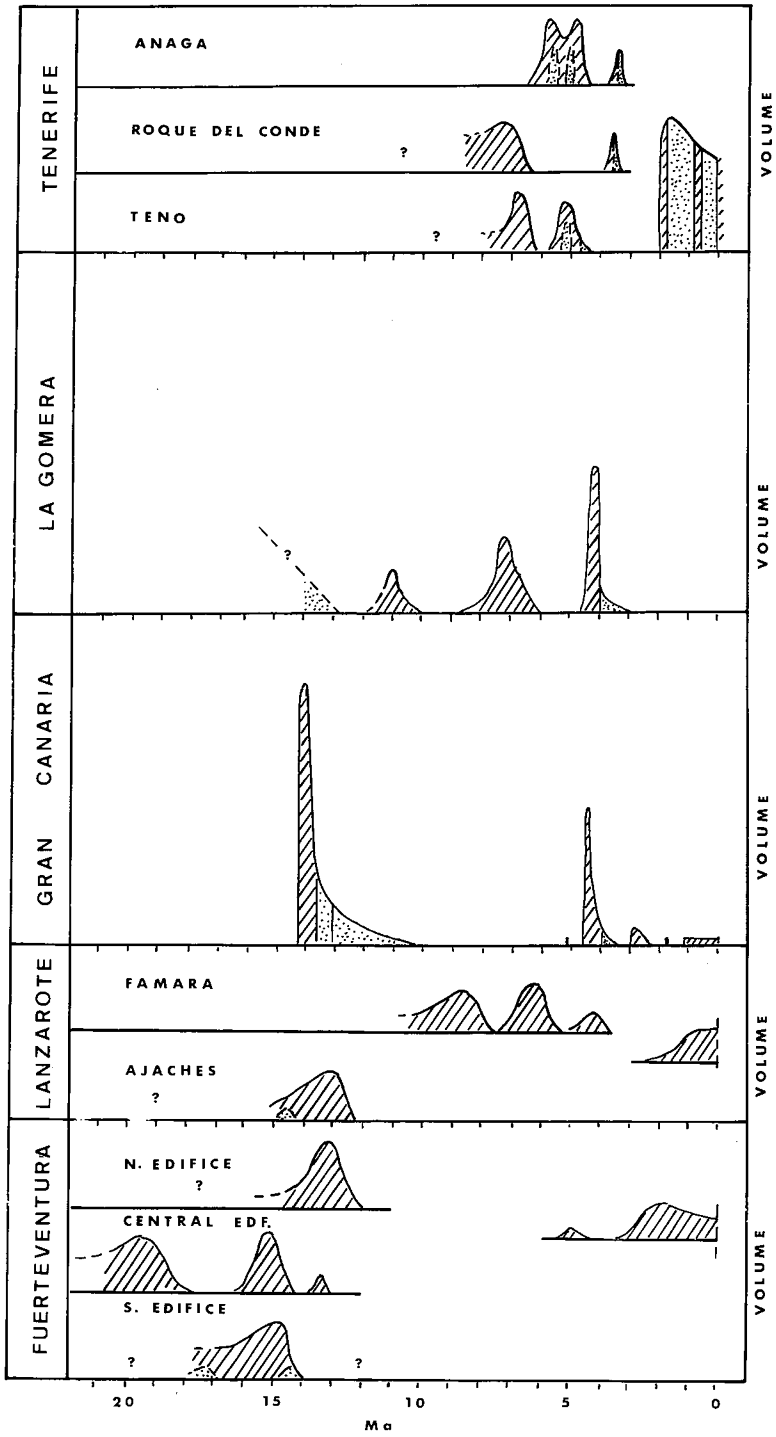

Fig. 8. Comparison between the temporal distribution and approximate volume (not to scale) of the volcanic cycles in the central and eastern Canary Islands. Gran Canaria redrawn from Schmincke (1981), La Gomera from Cantagrel et al. (1984) and Tenerife from Ancochea et al. (1990). Dotted: salic and intermediate materials; hatched: basic materials.

the activity within each edifice, which decreases northwards.

Not only the ages, but also the patterns of growth of the different edifices vary significantly. Apart from the case of Gran Canaria, with its very rapid rate of growth during a single pulse, the rest of the edifices of Series I were built during periods of a few million years, each one of them including smaller pulses separated by gaps, during which the edifices were partly destroyed by erosion and/or collapse episodes, with or without the direct intervention of volcanic processes (Ancochea et al., 1990). From the compositional point of view, there are also differences, in the central islands, especially in Gran Canaria and Tenerife, salic and intermediate differentiates are frequent, mainly towards the end of eruptive cycles, but in Fuerteventura and Lanzarote they are very scarce.

The volcaniclastic units present in the lower levels of Series I in Tenerife and La Gomera have been interpreted as the result of large landslide episodes caused by the rapid accumulation of volcanic materials, with the consequent instability of the edifices, similar to what happened in more recent times in Tenerife, where such landslides affected the Pliocene–Pleistocene edifices (Navarro and Coello, 1989; Ancochea et al., 1990). This kind of formation appears mainly in the northern edifice of Fuerteventura ("Formación Ampuyenta"). Similar formations have been described in other oceanic islands (Moore, 1964; Chevallier and Bachelery, 1981; Duffield et al., 1982; Vincent et al., 1989) as well as in continental volcanoes (Francis et al., 1985; Luhr and Prestgaard, 1988; Cantagrel and Briot, 1990).

The spatial pattern of growth is also different. Gran Canaria and La Gomera constitute central, isolated edifices separated from neighbouring islands by depths of 2000–3000 m. In the case of Tenerife, the three edifices of Series I have a triangular disposition, but they were substituted in the Upper Pliocene and Pleistocene by a central composite volcano and a northeastern "Dorsal". In Fuerteventura and Lanzarote the edifices are clearly part of a ridge which extends further NNE, with submarine volcanoes. In all the islands, except in La Gomera, Pleistocene–Recent activity with the appearance of scattered, multi-vent volcanism occurred.

A comparison between the Canaries and other oceanic archipelagos, particularly Hawaii (Stearns, 1946; Moore et al., 1982; Peterson and Moore, 1987), shows interesting analogies and differences. The initial and submarine stage of Hawaii is equivalent to the submarine volcanism of the basal complexes of Fuerteventura, La Gomera (Cendrero, 1969) and La Palma (Staudigel and Schmincke, 1984). The subaerial shield-building phase of Hawaii is comparable to the phase of construction of Series I edifices in the Canaries, sometimes ending with the eruption of viscous, differentiated lavas. The "erosional stage" is well defined in the Canaries, and the "re-activation stage" is represented by the eruption of the Plio–Quaternary series. Stages 6 (atoll stage) and 7 (late seamount stage) do not have their equivalent in the Canary Islands.

The main differences appear with regard to the temporal development of volcanism. First, the total duration of the activity, which in the case of the Canaries goes back, at least, to Oligocene times and possibly to the Paleocene or even the Upper Cretaceous (Robertson and Stillman, 1979). Second, the life of the individual edifices; in the Canary Islands, especially in Fuerteventura and Lanzarote, the growth of the large Series I volcanoes often extended for more than five million years, in several pulses interrupted by periods of quiescence and partial destruction of the edifices. Gran Canaria, according to McDougall and Schmincke (1976), corresponds to a model of large shield with a very rapid growth, in a few hundred thousands of years. Finally, the lavas of the Canaries are alkaline throughout the whole process, both during the main constructive period (Series I) and the post-erosional period, with a gradual increase in alkalinity with time (Hernández-Pacheco and Ibarrola, 1973; Fúster, 1975).

Considering that a very large part of the islands is below sea level and that older volcanic materials are likely to be present there, it seems that in this part of the ocean margin the thermal anomalies and the geodynamic conditions leading to the appearance of volcanic activity have persisted for a very long time, at least since Late Cretaceous and perhaps since even earlier stages in the opening of this part of the Atlantic, but this point remains as one of the major unresolved problems.

Acknowledgements

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Appendix—sample site locations and rock descriptions

Series I. Fuerteventura

Southern edifice (Jandía)

F.16.C. Barranco de los Escobones. 28° 03′ 40″ N, 14° 24′ 18″ W; 70 m.
Olivine–augite basalt flow. Partly altered olivine phenocrysts and augite in a fluidal groundmass of augite, olivine, plagioclase and opaques, limited carbonate fillings in cavities.

F.19.C. Punta de Jandía-Faro. 28° 03′ 35″ N, 14° 30′ 18″ W; 5 m.
Olivine–augite basalt flow. Abundant phenocrysts of augite and slightly altered olivine in a groundmass of olivine, augite, plagioclase and opaques.

F.50.AC. South of Casa del Mosquito. 28° 04′ 55″ N, 14° 24′ 03″ W; 450 m.
Trachyte. Microcrystalline rock with a few phenocrysts of sanidine, augite and amphibole in a groundmass with felspar, aegirine, sphene and opaques.

F.76.AC. Pico de la Zarza, southern side. 28° 04′ 30″ N, 14° 20′ 03″ W; 380 m.
Basalt flow with scarce phenocrysts of augite and plagioclase. Microcrystalline groundmass with plagioclase, augite, olivine and opaques.

F.73.AC. Pico de la Zarza, southern side. 28° 05′ 45″ N, 14° 21′ 05″ W; 750 m.
Ankaramite flow; phenocrysts of augite, olivine, amphibole and plagioclase; microcrystalline groundmass of plagioclase, augite, olivine and opaques.

F.17.C Montaña Azufra. 28° 05′ 20″ N, 14° 27′ 33″ W; 10 m.
Trachyte plug; microcrystalline rock with alkali felspar microliths and scarce phenocrysts of felspar and aegirine.

Central edifice

F.24.C. Montaña de Gran Tarajal. 28° 12′ 40″ N, 14° 01′ 28″ W; 140 m.
Ankaramite flow. Abundant phenocrysts of titanaugite and olivine slightly altered to iddingsite, in groundmass with plagioclase, augite, olivine and opaques.

FV.33.F. Tablero de las Estancias. 28° 20′ 35″ N, 14° 10′ 08″ W; 150 m.
Basalt flow with phenocrysts of augite, altered olivine and plagioclase in a fresh microcrystalline groundmass of plagioclase, olivine, augite and abundant opaques.

F.27.C. Faro de la Entallada. 28° 13′ 35″ N, 13° 56′ 45″ W, 175 m.
Olivine basalt flow; scarce phenocrysts of olivine partly altered to iddingsite, in a microcrystalline groundmass of plagioclase, augite, olivine and opaques.

F.58.AC. South of Morro de los Tarajales. 28° 11′ 20″ N, 14° 08′ 33″ W; 100 m.
Basalt plug. Augite, plagioclase and amphibole phenocrysts in fluidal groundmass with plagioclase, augite and opaques; some carbonate fillings.

F.59.AC. Atalaya de Pozo Negro. 28° 18′ 25″ N, 13° 55′ 58″ W; 320 m.
Trachybasalt flow. Microcrystalline rock with scarce phenocrysts of plagioclase in a groundmass of plagioclase, augite, opaques and biotite.

F.25.L. Huertas de Chilegua. 28° 15′ 00″ N, 14° 11′ 38″ W, 190 m.
Olivine–augite basalt flow. Phenocrysts of olivine and augite in a microcrystalline groundmass with plagioclase, olivine, augite and opaques.

F.60.AC. Tablero del Saladillo. 28° 18′ 30″ N, 13° 56′ 08″ W; 350 m.

Picritic basalt flow. Abundant phenocrysts of olivine and scarce augite in a groundmass of plagioclase, augite, olivine and opaques.

Northern edifice

F.1.C. Montaña Tindaya. 28° 35′ 05″ N, 13° 58′ 33″ W; 220 m.
Trachyte dome. Microcrystalline aggregate of alkali felspars and interstitial quartz; scarce altered mafics and opaques.

F.69.AC. Tostón-Cotillo. 28° 40′ 30″ N, 14° 00′ 35″ W; 5 m.
Plagioclase basalt flow. Phenocrysts of plagioclase and augite in a hipocrystalline groundmass of plagioclase, augite, olivine and interstitial biotite.

F.9.C. Punta de la Atalaya. 28° 29′ 50″ N, 13° 53′ 38″ W; 150 m.
Plagioclase trachybasalt flow. Plagioclase phenocrysts in a fluidal groundmass with plagioclase, olivine altered to iddingsite, augite opaques and glass.

F.71.AC. Southeast of Morro Carnero. 28° 34′ 45″ N, 13° 54′ 35″ W; 150 m.
Olivine–augite basalt flow. Abundant phenocrysts of partly altered olivine, augite and plagioclase in a groundmass of similar composition; very scarce carbonates.

FV.49.F. Tostón-Cotillo. 28° 39′ 50″ N, 14° 00′ 35″ W; 12 m.
Plagioclase basalt flow. Phenocrysts of plagioclase, altered olivine and augite in a groundmass of plagioclase, augite, olivine, opaques and interstitial biotite.

F.20.C. Montaña de Enmedio. 28° 29′ 10″ N, 13° 55′ 48″ W; 180 m.
Plagioclase basalt flow. Plagioclase phenocrysts and to a lesser extent augite and altered olivine; groundmass with plagioclase, augite, olivine and opaques.

F.30.C. Montaña del Campo. 28° 28′ 00″ N, 13° 58′ 35″ W; 500 m.
Trachybasalt flow. Scarce phenocrysts of plagioclase and augite; fluidal groundmass of plagioclase, augite and opaques.

F.52.AC. Pico de la Muda. 28° 34′ 00″ N, 13° 57′ 28″ W; 680 m.
Plagioclase–augite basalt flow. Abundant phenocrysts of plagioclase, augite and some olivine and opaques; coarse groundmass of a similar composition; scarce carbonates.

F.21.C. Morro de la Galera. 28° 29′ 55″ N, 13° 56′ 23″ W; 485 m.
Basalt flow. Scarce phenocrysts of augite, altered olivine and plagioclase; microcrystalline groundmass of a similar composition.

Series I. Lanzarote

Ajaches edifice

L.50.F. Punta Papagayo. 28°50′05″N, 13°47′08″W; 5 m.
Aphyric basalt flow; microcrystalline groundmass with olivine altered to iddingsite, plagioclase, opaques and slightly altered augite.

L.7.F. Castillo de la Coloradas. 28° 51′ 03″ N, 13° 48′ 33″ W; 5 m.
Slightly porphyritic basalt flow; olivine phenocrysts and some augite; groundmass with abundant plagioclase, augite and opaques.

L.16.F. Pico Redondo. 28° 53′ 30″ N, 13° 46′ 53″ W; 260 m.
Aphyric basalt flow; microphenocrysts of olivine; abundant zoned plagioclase, augite and opaques.

L.10.F. Rubicón, north of Papagayo. 28° 51′ 05″ N, 13° 46′ 53″ W; 40 m.
Trachyte dome. Abundant anorthoclase phenocrysts; groundmass of anorthoclase and scarce alteration products, pyroxenes and opaques. K–Ar determination on anorthoclase phenocrysts.

L.19.F. Pico Redondo. 28° 53′ 45″ N, 13° 46′ 28″ W; 500 m.
Aphyric trachybasalt flow; scarce olivine phenocrysts; groundmass with abundant plagioclase and some augite and opaques.

L.14.F. South of Atalaya de Femés. 28° 54′ 35″ N, 13° 46′ 48″ W; 60 m.
Porphyritic basalt flow; slightly serpentinized olivine and some augite phenocrysts; groundmass with plagioclase, opaques and augite.

L.15.F. West of Ajaches, south of Hacha Chica. 28° 51′ 40″ N, 13° 45′ 53″ W; 60 m.
Slightly porphyritic basalt flow; phenocrysts of olivine and plagioclase; groundmass with plagioclase, opaques and pyroxenes.

L.9.F. North of Punta Papagayo. 28° 51′ 20″ N, 13° 47′ 08″ W; 40 m.
Aphyric basalt flow; micro and cryptocrystalline groundmass with plagioclase microliths and small opaques.

Other outcrops in the south

L.4.F. Salinas del Janubio, base of Series I. 28° 55′ 50″ N, 13° 49′ 03″ W; 5 m.
Slightly porphyritic basalt flow; phenocrysts of plagioclase and anorthoclase; scarce serpentinized olivine;

groundmass of plagioclase, augite and opaques.

L.5.F. Salinas del Janubio, top of Series I. 28° 55' 45" N, 13° 57' 13" W; 15 m.
Ankaramite flow; abundant olivine phenocrysts, groundmass of augite, opaques and scarce plagioclase.

L.12.F. Tías, Cantera de las Majadas. 28° 57' 25" N, 13° 37' 48" W; 160 m.
Porphyritic ankaramite flow; abundant olivine phenocrysts; groundmass of augite, opaques, scarce plagioclase and some nepheline.

Famara edifice

L.24.F. West of Famara, 4ª Galería. 29° 08' 20" N, 13° 31' 15" W; 0 m.
Porphyritic basalt flow; slightly serpentinized olivine phenocrysts; fresh groundmass of plagioclase, augite and opaques; very scarce (<0.5%) cavities with fillings of zeolites and calcite amigdules.

L.2.F. Lomo de Zalahar. 29° 13' 00" N, 13° 27' 38" W; 50 m.
Porphyritic ankaramite flow; olivine and some augite phenocrysts; groundmass with augite and opaques; interstitial nepheline.

L.25.F. West of Famara, 2ª Galería. 29° 07' 25" N, 13° 31' 38" W; 100 m.
Ankaramite flow; finely porphyritic with abundant olivine and pyroxene phenocrysts; groundmass of pyroxene, opaques and plagioclase.

L.35.F. Peña Pequeña. 29° 07' 00" N, 13° 29' 48" W; 480 m.
Porphyritic ankaramite flow, abundant olivine phenocrysts; groundmass of plagioclase, augite and opaques.

L.33.F. C. del Norte, km 24. 29° 07' 40" N, 13° 30' 38" W; 440 m.
Porphyritic ankaramite flow; partly iddingsitized olivine phenocrysts; groundmass of pyroxenes and opaques and scarce plagioclase.

L.45.F. Famara scarp. 29° 12' 00" N, 13° 24' 13" W; 340 m.
Porphyritic ankaramite flow, abundant olivine and some augite phenocrysts; groundmass of plagioclase, opaques and augite.

L.44.F. Orzola (Valle Chico). 29° 13' 10" N, 13° 29' 43" W; 0 m.
Porphyritic basanite; fresh olivine phenocrysts; groundmass of olivine and opaques; some plagioclase and nepheline; biotite associated with opaque agglomerates.

L.1.F. Orzola (Valle Chico). 29° 13' 10" N, 13° 27' 43" W; 20 m.
Porphyritic ankaramite flow; olivine phenocrysts partly altered to iddingsite; groundmass with augite, opaques and poikilitic plagioclase; some altered nepheline (?).

L.31.F. C. de Tabayesco, km 3. 29° 07' 25" N, 13° 29' 23" W; 200 m.
Porphyritic basalt flow; partly iddingsitized olivine phenocrysts; groundmass of pyroxenes, opaques and plagioclase.

L.46.F. Famara Scarp. 29° 11' 40" N, 13° 29' 30" W; 370 m.
Porphyritic ankaramite flow; abundant olivine and augite phenocrysts; groundmass with pyroxenes, opaques and plagioclase.

Post-Miocene Series. Fuerteventura

488.4. Barranco de Ajuí. 28° 23' 20" N, 14° 09' 03" W; 25 m.
Olivine basalt flow; olivine phenocrysts; groundmass of plagioclase, olivine, augite and abundant opaques.

L.11.F. Barranco de los Molinos. 28° 32' 05" N, 14° 02' 43" W; 50 m.
Olivine basalt flow; slightly altered olivine phenocrysts; groundmass of olivine, opaques, augite and plagioclase.

491.5. Puerto de los Molinos. 28° 32' 25" N, 14° 03' 28" W; 15 m.
Olivine basalt flow; olivine phenocrysts; groundmass of olivine, opaques, augite and plagioclase.

L.67.AC. Tablero de Golfete. 28° 28' 45" N, 14° 05' 08" W; 40 m.
Olivine nephelinite flow; partly altered olivine phenocrysts; groundmass of olivine, opaques, augite and interstitial nepheline; cavities with very scarce fillings of carbonate and zeolites.

L.8.F. Barranco de Antigua. 28° 22' 05" N, 13° 54' 38" W; 60 m.
Basanite flow; partly altered olivine and augite phenocrysts; groundmass of olivine, opaques, augite and scarce plagioclase and nepheline; carbonate fillings.

492.6. Aljibe de la Cueva, Tostón-Cotillo. 28° 38' 40" N, 14° 00' 53" W; 15 m.
Basalt flow; olivine phenocrysts in a groundmass of olivine, opaques, augite and plagioclase.

487.3. Barranco de la Herradura. 28° 31' 30" N, 13° 50' 13" W; 12 m.
Basanite flow; abundant olivine phenocrysts; ground-

mass of olivine, opaques, augite, interstitial plagioclase and nepheline (?).

485.1. El Veril de Santiago. 28° 35' 57" N, 13° 49' 43" W; 30 m.
Olivine basalt flow; olivine phenocrysts; groundmass of olivine, opaques, augite and plagioclase.

L.68.AC. Barranco del Janubio. 28° 33' 45" N, 14° 01' 28" W; 60 m.
Olivine basalt flow; olivine microphenocrysts; groundmass of olivine, opaques, augite and plagioclase.

486-2. La Salina. 28° 37' 35" N, 13° 49' 38"; 5m.
Olivine basalt flow; phenocrysts of olivine; groundmass of augite, plagioclase, olivine and opaques.

Post-Miocene Series. Lanzarote

L.23.F. Montaña Roja. 28° 51' 40" N, 13° 52' 18" W; 10 m.
Aphyric basalt flow; abundant plagioclase, slightly altered olivine, augite and interstitial opaques.

L.51.F. Presa de Mala. 29° 06' 00" N, 13° 28' 23" W; 120 m.
Porphyritic olivine basalt flow; very slightly altered olivine phenocrysts; fine-grained groundmass of augite, opaques and plagioclase; small cavities with carbonate fillings.

L.43.F. Montaña Temeje, Guatiza. 29° 04' 30" N, 13° 29' 38" W; 120 m.
Basalt flow; olivine phenocrysts; microlithic groundmass of opaques, augite and plagioclase.

L.48.F. Salinas de Matagorda, Punta Lima. 28° 55' 45" N, 13° 36' 48" W; 7 m.
Basalt flow; small olivine phenocrysts; groundmass of augite, opaques and plagioclase.

L.39.F. Guanapay, Meseta de la Torre. 29° 02' 55" N, 13° 33' 08" W; 390 m.
Aphyric trachybasalt flow; olivine intergrown with opaques; groundmass of slightly altered augite and plagioclase.

L.38.F. North of Playa Quemada. 28° 54' 35" N, 13° 42' 58" W; 20 m.
Porphyritic basalt flow; fresh olivine phenocrysts; cryptocrystalline groundmass of plagioclase and opaques.

L.6.F. Salinas del Janubio. 28° 56' 00" N, 13° 48' 53" W; 50 m.
Basalt flow; abundant phenocrysts of olivine; fluidal groundmass of opaques, augite and plagioclase.

L.47.F. Tinajo, Morro de S. Roque. 29° 03' 10" N, 13° 40' 28" W; 240 m.
Porphyritic basalt flow; small olivine phenocrysts; groundmass of augite and opaques; very scarce plagioclase.

L.42.F. Tahiche. 29° 00' 00" N, 13° 31' 53" W; 170 m.
Trachybasalt flow; small olivine phenocrysts; groundmass of abundant opaques, augite and plagioclase.

L.41.F. Northeast of Tahiche. 29° 01' 00" N, 13° 31' 53" W; 130 m.
Trachybasalt flow; small olivine phenocrysts; plagioclase-rich groundmass with augite and opaques.

L.49.F. Playa de los Pocillos. 28° 55' 30" N, 13° 38' 03" W; 15 m.
Basalt flow; augite and fresh olivine phenocrysts; abundant plagioclase in groundmass with pyroxene and opaques.

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